Lecture P1: Introduction to C

```
#include <stdio.h>
int main(void) {
  printf("This is a C program.\n");
  return 0;
}
```

Learning to Program

Programming is learned with practice and patience.

- Don't expect to learn solely from these lectures.
- Do exercises.
- Experiment and write lots of code.

Do reading.

- Finish King Chapters 1-6 today!

Aspects of learning to program.

- Language syntax.
- Algorithms.
- Libraries.
- These are different skills and learning processes.

C Background

Born along with Unix in the early 1970's.

- One of most popular languages today.

C Features.

- Concise.
- Widespread usage.
- Exposes low-level details of machine.

Consequences.

- Positive: you can do whatever you want.
- Negative: you can do whatever you want.

An Example

Print a table of values of function f(x) = $2 - x^3$. A first attempt:

table1.c

```
#include <stdio.h>

int main(void) {
  double x, y;

  printf(" x    f(x)\n");
  x = 0.0;
  y = 2.0 - x*x*x;
  printf("%4.1f %6.3f\n", x, y);
  x = 0.1;
  y = 2.0 - x*x*x;
  printf("%4.1f %6.3f\n", x, y);
  .  .  .
  x = 1.9;
  y = 2.0 - x*x*x;
  printf("%4.1f %6.3f\n", x, y);
  return 0;
}
```

Printf Library Function

Contact between your C program and outside world.

- Puts characters on "standard output."
- By default, stdout is the "terminal" that you're typing at.

Internally, all numbers represented in BINARY (0's and 1's).

- `printf()` displays more useful representation (`int`, `double`).

Formatted output.

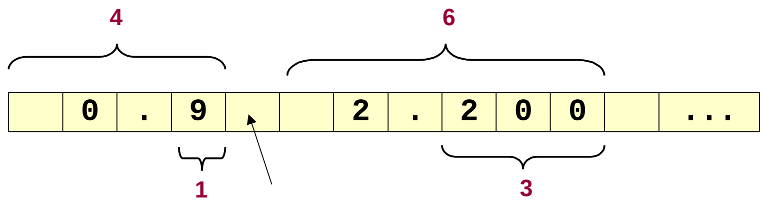
- How do you want the numbers to look?
  - integers, how many digits?
  - real numbers, how many digits after decimal place?
- Very flexible.

Anatomy of Printf

%f to print double

'\n' is newline character

```
double x, y;
x = 0.927;
y = 2.2;
printf("%4.1f %6.3f\n", x, y);
```



space in `printf` statement

Running a Program in Unix

When you type commands, you are controlling an abstract machine called the "Unix shell."

- Compile: convert the program from human's language (C) to machine's language.
  - 1st try: syntax errors in C program
  - eventually, a file named a.out
- Execute: start the machine. (at first instruction in `main`)
  - 1st try: semantic errors in C program
  - eventually, desired "printf" output

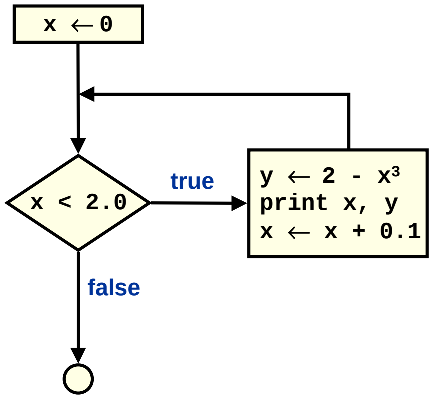
Unix

```
% gcc table.c
% a.out

x    f(x)
0.0  2.000
0.1  1.999
0.2  1.992
0.3  1.973
0.4  1.936
0.5  1.875
0.6  1.784
0.7  1.657
0.8  1.488
0.9  1.271
1.0  1.000
1.1  0.669
1.2  0.272
1.3 -0.197
1.4 -0.744
1.5 -1.375
1.6 -2.096
1.7 -2.913
1.8 -3.832
1.9 -4.859
```

Anatomy of a While Loop

Previous program repeats the same code over and over.

- Repetitive code boring to write and hard to debug.
- Use while loop to repeat code.



```
x = 0.0;
while (x < 2.0) {
  y = 2 - x*x*x;
  printf("%f %f\n", x, y);
  x = x + 0.1;
}
```

C code

While Loop Example

Print a table of values of function f(x) = 2 - x^3. A second attempt.

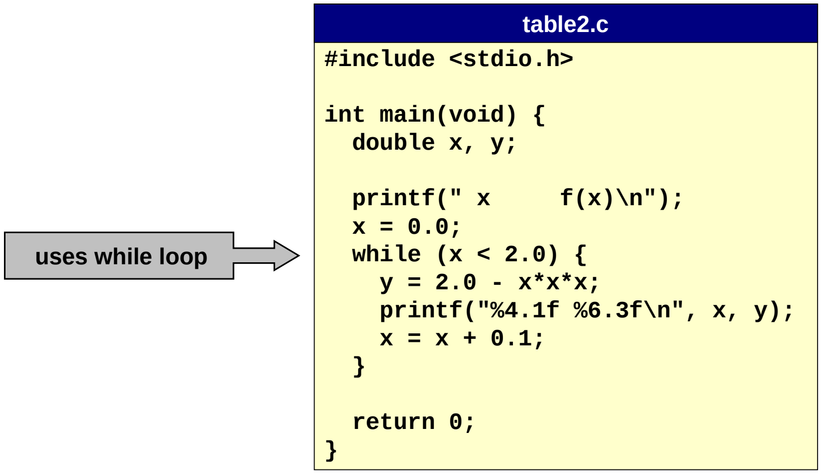


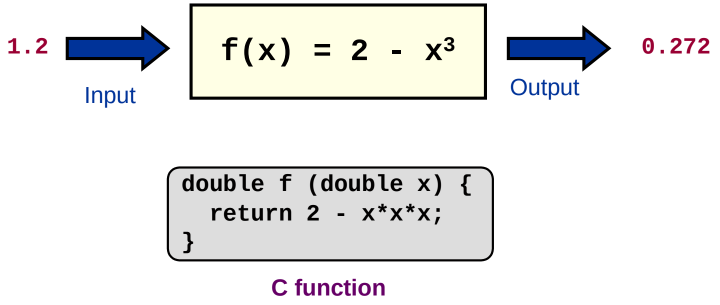
table2.c

```
#include <stdio.h>

int main(void) {
  double x, y;

  printf(" x     f(x)\n");
  x = 0.0;
  while (x < 2.0) {
    y = 2.0 - x*x*x;
    printf("%4.1f %6.3f\n", x, y);
    x = x + 0.1;
  }

  return 0;
}
```

Anatomy of a Function

Convenient to break up programs into smaller modules or functions.

- Layers of abstraction.
- Makes code easier to understand.
- Makes code easier to debug.
- Makes code easier to change later on.



```
double f (double x) {
  return 2 - x*x*x;
}
```

C function

Anatomy of a Function

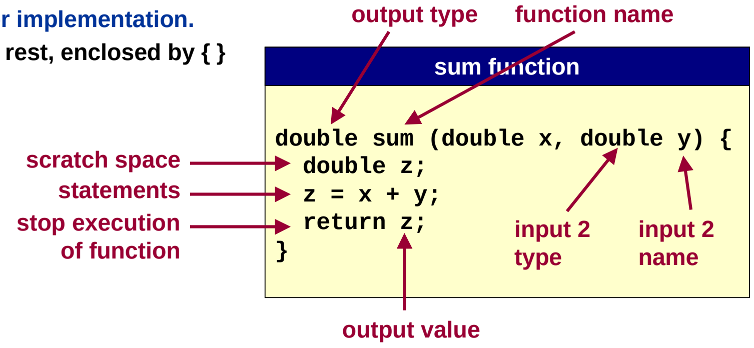
C function similar to mathematical function.

Prototype or interface is first line of C function.

- specifies input argument(s) and their types
  - can be integers, real numbers, strings, vectors, user-defined
- specifies return value

Body or implementation.

- The rest, enclosed by { }



sum function

```
double sum (double x, double y) {
  double z;
  z = x + y;
  return z;
}
```

Anatomy of a C Program

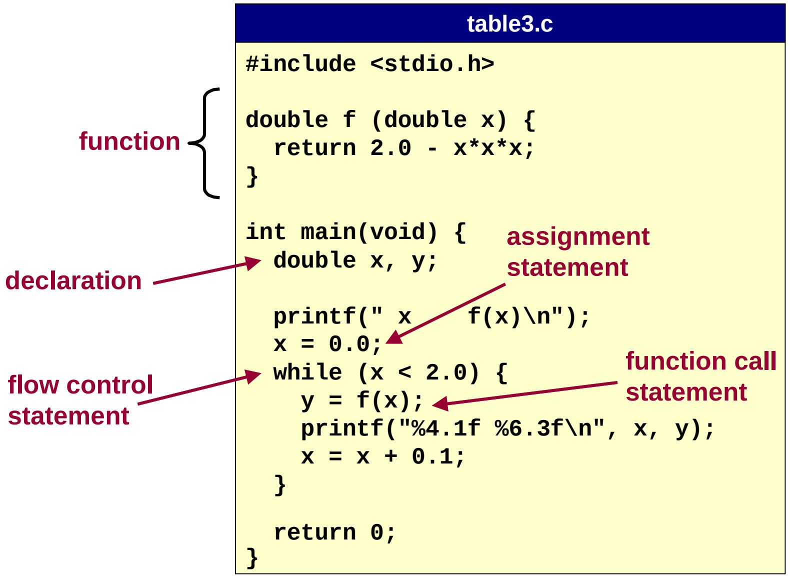


table3.c

```
#include <stdio.h>

double f (double x) {
  return 2.0 - x*x*x;
}

int main(void) {
  double x, y;

  printf(" x     f(x)\n");
  x = 0.0;
  while (x < 2.0) {
    y = f(x);
    printf("%4.1f %6.3f\n", x, y);
    x = x + 0.1;
  }

  return 0;
}
```

Random Integers

Print 10 "random" integers.

- Library function `rand()` in `stdlib.h` returns integer between 0 and `RAND_MAX` (32,767 = 2^{16} - 1 on arizona).

int.c

```
#include <stdio.h>
#include <stdlib.h>

int main(void) {
  int i;
  for (i = 0; i < 10; i++)
    printf("%d\n", rand());
  return 0;
}
```

Unix

```
% gcc int.c
% a.out
16838
5758
10113
17515
31051
5627
23010
7419
16212
4086
```

Random Integers

Print 10 "random" integers between 0 and 599.

- No precise match in library.
- Try to leverage what's there to accomplish what you want.

int600.c

```
#include <stdio.h>
#include <stdlib.h>

int randomInteger(int n) {
  return rand() % n;
}

int main(void) {
  int i;
  for (i = 0; i < 10; i++)
    printf("%d\n", randomInteger(600));
  return 0;
}
```

p % q gives remainder of p divided by q

Unix

```
% gcc int600.c
% a.out
168
  5
  1
175
310
562
230
341
16
386
```

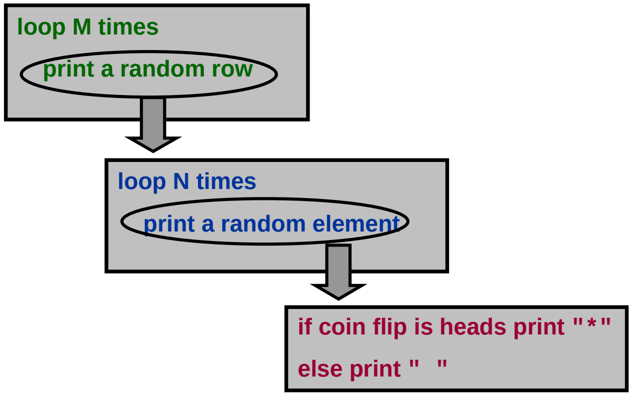
Random M x N Pattern

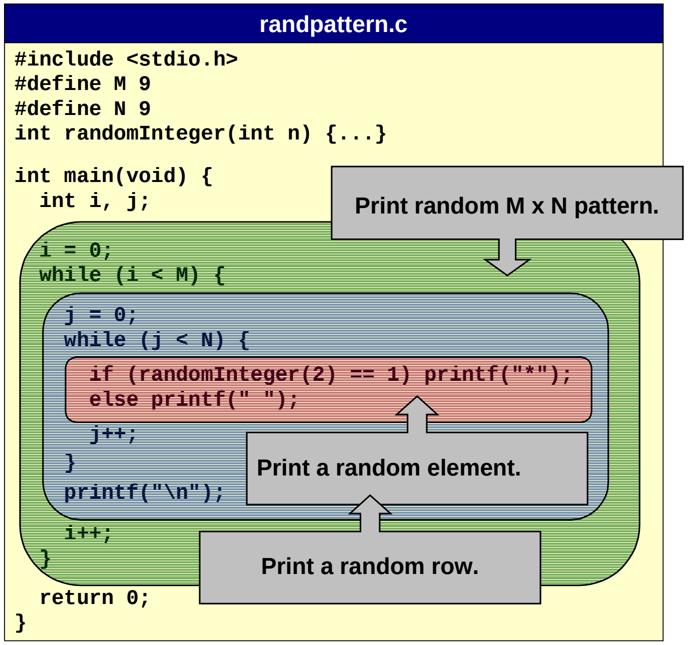
```
 * * * *         ** ***           * **   **
* * * * *           **** *        ***    **
 * * * *             *   *          * * *
* * * * *        * ***            **  * **
 * * * *           **** **        *  *
* * * * *           *   **        *** *** *
 * * * *          ***    *        **     *
* * * * *         **** ***            *  **
 * * * *           *   ***        *     ***

 **  **          *     ***        *   * ***
  **  **            * *            ** *   *
*  **  **           **   *         **** * *
**  **  *        *****   *        * **  **
 **  **          ** * ****         *
  **  **         **  *** *          ***
*  **  **            ***          *      **
**  **  *         * *             *  *  *
 **  **           **   * *         *     **
```

Random M x N Pattern

Top-down design.

- Break a big problem into smaller subproblems.
- Break down subproblems into sub-subproblems.
- Repeat until all details filled in.





randpattern.c

```
#include <stdio.h>
#define M 9
#define N 9
int randomInteger(int n) {...}

int main(void) {
  int i, j;
  i = 0;
  while (i < M) {
    j = 0;
    while (j < N) {
      if (randomInteger(2) == 1) printf("*");
      else printf(" ");
      j++;
    }
    printf("\n");
    i++;
  }
  return 0;
}
```

Print random M x N pattern.

Print a random element.

Print a random row.

Libraries

How is library function `printf()` created?

- User doesn't need to know details (see COS 217).
- User doesn't want to know details (abstraction).

How is library function `rand()` created?

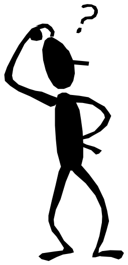
- Linear feedback shift register? Cosmic rays?
- Depends on compiler and operating system.
- Caveat 1: "random" numbers are not really random.
- Caveat 2: on many systems, our `randomInteger()`is very poor.

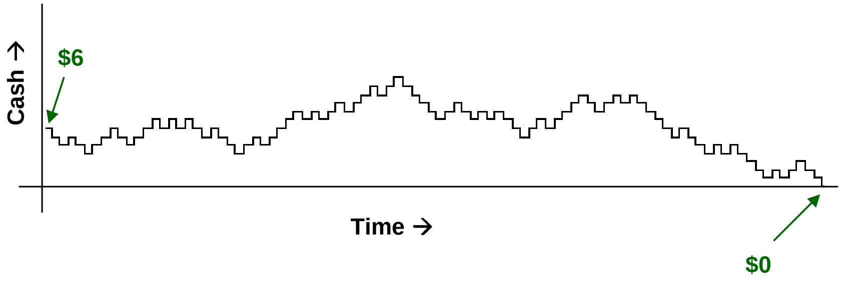
Moral: check assumptions about library function.

Gambler's Ruin

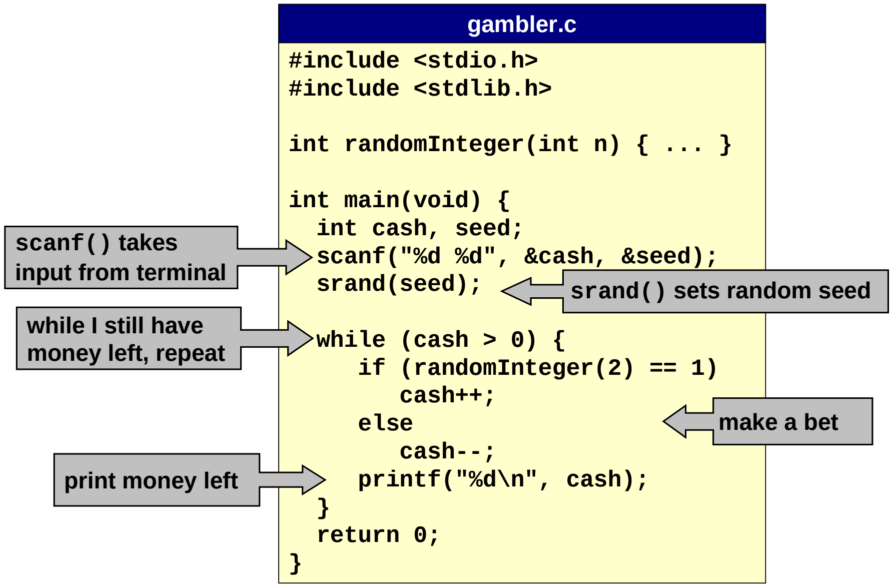
Simulate gambler placing $1 even bets.

- Will gambler always go broke.
- If so, how long will it take if gambler starts with $c?





Gambler's Ruin



gambler.c

```
#include <stdio.h>
#include <stdlib.h>

int randomInteger(int n) { ... }

int main(void) {
  int cash, seed;
  scanf("%d %d", &cash, &seed);
  srand(seed);

  while (cash > 0) {
     if (randomInteger(2) == 1)
        cash++;
     else
        cash--;
     printf("%d\n", cash);
  }
  return 0;
}
```

`scanf()` takes input from terminal

`srand()` sets random seed

while I still have money left, repeat

make a bet

print money left

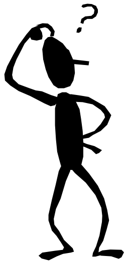
Gambler's Ruin

Simulate gambler placing $1 even bets.
Q. How long does the game last if we start with $c ?

Unix

```
% gcc gambler.c

% a.out          % a.out
4 543            4 1234
3                3
4                2
5                3
4                4
3                3
4                4
3                5
2                6
1                7
0                6
                 7
                 8
                 9
```

Hmmm.



Gambler's Ruin

Simulate gambler placing $1 even bets.
Q. How long does the game last if we start with $c ?

Unix

```
% gcc gambler.c

% a.out          % a.out
4 543            4 1234
***              ***
****             **
*****            ***
****             ****
***              ***
****             ****
***              *****
**               ******
*                *******
                 ******
                 *******
                 ********
                 *********
```

To print plot, replace:

```
printf("%d\n", cash);
```

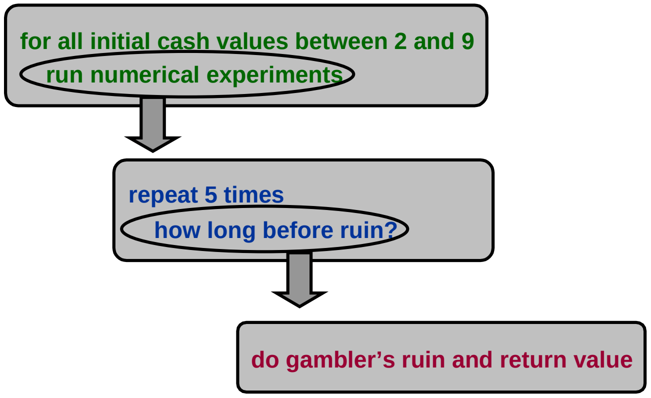
with

```
i = cash;
while (i > 0) {
   printf("*");
   i--;
}
printf("\n");
```

Top-Down Design of Numerical Experiment

Goal: run experiment to see how long it takes to go broke.

- Find out how this changes for different values of c.



for all initial cash values between 2 and 9
run numerical experiments
repeat 5 times
how long before ruin?
do gambler's ruin and return value

Gambler's Ruin Experiment

single experiment
(code as before)

gexperiment.c

```
#include <stdlib.h>
#include <stdlib.h>

int randomInteger(int n) { ... }

int doit(int cash) {
  int cnt = 0;
  while (cash > 0) {
     if (randomInteger(2) == 1)
        cash++;
     else
        cash--;
     cnt++;
  }
  return cnt;
}
```

Gambler's Ruin Experiment

repeat for all initial cash values 2 to 9

repeat 5 times

gexperiment.c (cont)

```
int main(void) {
   int cash, t;

   cash = 2;
   while (cash < 10) {
      printf("%2d ", cash);
      t = 0;
      while (t < 5) {
         printf("%7d", doit(cash));
         t++;
      }
      printf("\n");
      cash++;
   }

   return 0;
}
```

Gambler's Ruin Experiment

Unix

```
% gcc gexperiment.c
% a.out
                        # bets

 2         2      6    304      2      2
 3        33     17     15     53     29
 4        22   1024   7820     22     54
 5       243     25     41      7    249
 6       494     14    124    152     14
 7       299     33    531     49     93
 8       218  10650     36  42048    248
 9 174090315  83579    299    759     69
```

initial cash

How long will it take to go broke?

Layers of abstraction.

- Random bit → gambler's ruin sequence → experiment.

Programming Advice

Understand your program.

- What would the machine do?

Read, understand, and borrow from similar code.

Develop programs incrementally.

- Test each piece separately before continuing.
- Plan multiple lab sessions.

Debugging

Find the FIRST bug and fix it.

Syntax error - illegal C program.

- Compiler error messages are good - tell you what you need to change.

Semantic error - wrong C program.

- Use "printf" method.

Always a logical explanation.

Enjoy the satisfaction of a fully functional program!

Programming Style

Concise programs are the norm in C.

Your goal: write READABLE and EFFICIENT programs.

- Use consistent indenting.
  - automatic indenting in emacs
- Choose descriptive variable names.
- Use comments as needed.

"Pick a style that suits you, then
use it consistently."

-Kernighan and Ritchie

Summary

Lots of material.

C is a structured programming language.

- Functions, loops.
- Simple but powerful tools.

Programming maturity comes with practice.

- Everything seems simpler in lecture and textbooks.
- Always more difficult when you do it yourself!
- Learn main ideas from lecture, learn to program by writing code.

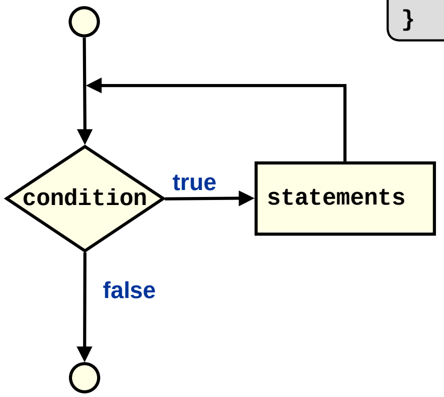
Lecture P1: Supplemental Notes

Anatomy of a While Loop

The while loop is a common repetition structure.

```
while (condition) {
  statements;
}
```

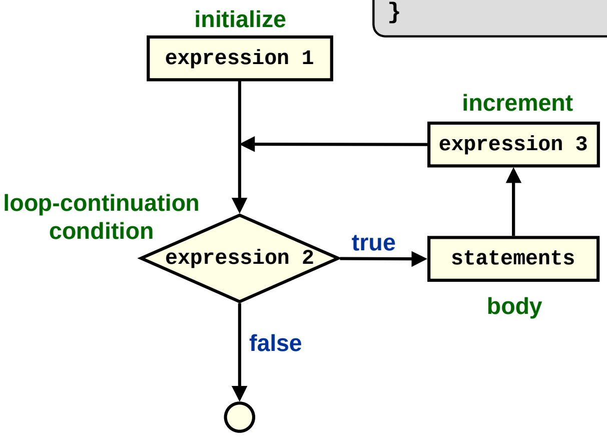
while loop



Anatomy of a For Loop

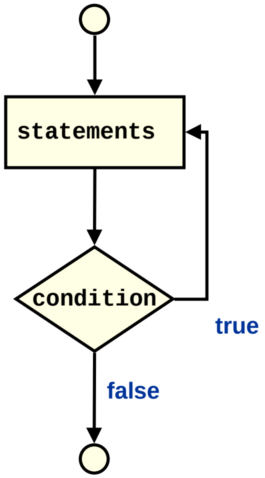
The for loop is another common repetition structure.

```
for (expr1; expr2; expr3) {
  statements;
}
```



Anatomy of a Do-While Loop

The do-while loop is not-so-common repetition structure.



```
do {
  statements;
} while (condition)
```

do-while loop

For Loop Example

Print a table of values of function f(x) = 2 - x^3. A fourth attempt.

uses for loop

table4.c

```
#include <stdio.h>

int main(void) {
  double x, y;

  printf(" x     f(x)\n");
  for (x = 0.0; x < 2.0; x = x + 0.1) {
    y = 2 - x*x*x;
    printf("%4.1f %6.3f\n", x, y);
  }

  return 0;
}
```

Final Attempt

Print a table of values of function f(x) = 2 - x^3. A fifth attempt.

table5.c

```
#include <stdio.h>

double f (double x) {
  return 2.0 - x*x*x;
}

int main(void) {
  double x;

  printf(" x     f(x)\n");
  for (x = 0.0; x < 2.0; x += 0.1)
    printf("%4.1f %6.3f\n", x, f(x));
  return 0;
}
```

x += 0.1 is shorthand in C for x = x+ 0.1

no need for { } if only one statement

What is a C Program?

C PROGRAM: a sequence of FUNCTIONS that manipulate data.

- `main()` function executed first.

A FUNCTION consists of a sequence of DECLARATIONS followed by a sequence of STATEMENTS.

- Can be built-in like `printf(...)`.
- Or user-defined like `f(x)` or `sum(x, y)`.

A DECLARATION names variables and defines type.

- double `double x;`
- integer `int i;`

A STATEMENT manipulate data or controls execution.

- assignment: `x = 0.0;`
- control: `while (x < 2.0) {...}`
- function call: `printf(...);`

Random Real Numbers

Print 10 "random" real numbers between 0.0 and 1.0.

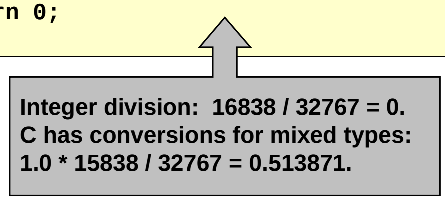
- No precise match in library.
- Try to leverage what's there to accomplish what you want.

real.c

```
#include <stdio.h>
#include <stdlib.h>

int main(void) {
  int i;
  for (i = 0; i < 10; i++)
    printf("%f\n", 1.0 * rand() / RAND_MAX);
  return 0;
}
```

Unix

```
% gcc real.c
% a.out
0.513871
0.175726
0.308634
0.534532
0.947630
0.171728
0.702231
0.226417
0.494766
0.124699
```



Integer division: 16838 / 32767 = 0.
C has conversions for mixed types:
1.0 * 15838 / 32767 = 0.513871.